Salmon Matrix Review

By

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Executive Summary

In March 1997, federal and state agencies developed an aquatic matrix for the Pacific Lumber Company Habitat Conservation Plan (hereafter "salmon matrix"). The matrix puts forth a condition for the landscape which has been determined to be properly functioning in order to meet the habitat needs of anadromous salmonids and other aquatic species in northern California on Pacific Lumber Company properties in Humboldt County. The CIE review panel was provided four questions to consider in reviewing the utility of the salmon matrix as a tool to maintain habitats of endangered salmon populations in northern California. The following are a summary of my responses to the four questions.

1. *Are the metrics used in the matrix appropriate?*

The metrics capture many of the physical habitat attributes that are generally considered important for salmonid fishes in small streams. The metrics are relatively specific and quantitative for instream variables, but considerably vaguer for out of channel and upslope conditions. Without more specific consideration of upslope (catchment) conditions application of the matrix provides only a snapshot of current stream condition with little ability to predict future trends in habitat condition. It is difficult to evaluate whether some of the metrics are appropriate to the recovery of endangered salmon in the Redwood area because of a lack of regional knowledge on salmon life history and habitat requirements.

2. *Are the values for the metrics appropriate?*

In some cases (e.g., substrate fines, wood, temperature, turbidity) the values should be updated with data from the redwood area- especially data from streams in previously logged areas that are now considered to be 'properly functioning'.

In all cases the values should have some measure of variability with them to represent the natural variation that occurs both among reaches, and among streams. Rather than using matrix metric values as thresholds, the goal should be to determine if streams under consideration have an appropriate range of variability in matrix attributes.

Special consideration should be given to the downstream consequences of matrix values for temperature and possibly turbidity. For example, application of upper thresholds for temperature in small headwater streams might mean that downstream areas of the catchment might be rendered unsuitable as habitat.

3. *Which metrics are appropriate for the assessment, monitoring, and adaptive management of salmonids?*

There are perhaps 2 issues imbedded in this question- which metrics are appropriate for the monitoring of current and future land-use practices on aquatic habitats, and which metrics are appropriate for the monitoring of fish populations themselves?

On the land-use question the major problem is that most of the matrix metrics are unlikely to be responsive to land-use practices on a time scale that is going to be useful on the ground. It is proposed that suspended sediments (as indexed by turbidity) during low (or some other standard part of the hydrograph) be considered as a responsive, easy to measure, metric for management activities. Similarly, catchment-wide temperature monitoring may also be a useful measure of the impacts of changes in forest cover. Tracking land-use in catchments should also be used as an indicator of likely trends in aquatic habitats (see question 4).

Monitoring fish populations is more problematic, as estimating abundances is a difficult task. Indirect measures, such as localized estimates of abundance, relative abundance, growth and distribution may provide inference about the function of habitats, and changes that might of occurred as a result of management actions. But, ultimately, understanding overall trends (and risks of extirpation) will require detailed monitoring, perhaps at a few index sites.

4. *How should instream and riparian metrics be functionally and practically linked with upslope processes?*

Some of the change in aquatic habitats and biota is associated with upslope land-use, irrespective of the condition of the immediate riparian area. Sediment and temperature are two measures that link immediate impacts of land-use changes on aquatic habitats. However, the impacts of upland practices on instream habitats are predict with certainty because they are long-term and cumulative, and because infrequent catastrophic events can be extremely important.

Measures of catchment landcover should be included in the matrix, and consideration given to a matrix metric that addresses the rate of change in catchment land-use that track changes towards or away from conditions that are likely to lead to improvements (or at least maintenance) of aquatic conditions. Development of this metric is possible with GIS land-use databases and some of the instream sampling that is currently underway.

1. Background and Summary of Panel Activities

In March 1997, federal and state agencies developed an aquatic matrix for the Pacific Lumber Company Habitat Conservation Plan (hereafter "salmon matrix"). The matrix puts forth a condition for the landscape which has been determined to be properly functioning in order to meet the habitat needs of anadromous salmonids and other aquatic species in northern California on Pacific Lumber Company properties in Humboldt County. The CIE review panel was asked to address four questions about the matrix:

1. Are the metrics used in the matrix appropriate for assessing aquatic and associated riparian habitat conditions to meet the needs for threatened and candidate salmonid species? If not, which metrics would be appropriate and at what landscape scales?

2. Are the values provided for the metrics appropriate for assessing aquatic and associated riparian habitat condition to meet the needs of threatened and candidate salmonid species in coastal redwood systems? If not, which values would be appropriate and at what landscape scales?

3. Which metrics are the most appropriate for the assessment, monitoring, and adaptive management of aquatic candidate salmonid species in coastal redwood systems?

4. How should in-stream and riparian metrics be functionally and practically linked with upslope and watershed scale processes that, in part, determine their expression?

The panel and its activities

The review panel consisted of M. Bradford, Fisheries and Oceans Canada and Simon Fraser University; R. Cunjak, University of New Brunswick; R. Marsden, Oklahoma State University; L. Marshall, Fisheries and Oceans Canada; and C. Soulsby, University of Aberdeen. John Clancey (NMFS) ably chaperoned the group during their visit to the region.

The review panel met in Arcata CA, from November 27 to 30, 2000. On November 27, a series of presentations by J. Clancey (NMFS), G. Bryant (NMFS), B. Conden (CFG), G. Bryant (NMFS), B. Trush (Consultant), S. Flanigan (NMFS) and R. Klein (NPS) over a full day provided a background of the area and the issues. On November 28 the panel travelled to Prairie Creek and environs with J. Clancey, R. Klein, and E. Bell (Stillwater Sciences) to inspect old-growth conditions. On the 29th the group travelled to the Eel River to inspect streams impacted by mass wasting, and met with M. Tauzer (NMFS), Maryann Madej (USGS), and S. Kramer (Stillwater Sciences). On the 30th the panel visited Simpson Timber Co. lands to review road construction issues, and observe active forestry, and met with L. Reid (USFS) and S. Flanigan (NMFS). The panel left Arcata on January 30th and December 1, 2000 to prepare their independent reports.

2. Background issues for the California salmon habitat matrix.

It has been proposed that the matrix can serve as a blueprint for assessing the status of salmon streams in the Redwood area in relation to land-use practices (particularly logging). As a fisheries scientist, I focus on the implications of the application of the matrix for endangered salmon populations, with emphasis on coho salmon. I begin by reviewing background material on some of the key issues.

Why do salmon (particularly coho salmon) become endangered?

The review panel was struck by absence of links between both instream and upslope habitat measures and fish parameters, and by the general lack of quantitative data of on fish populations from the Redwood area. A review of the population dynamics of coho salmon (particularly populations at low abundance) can help to identify the habitat issues and approaches most likely to achieve recovery of these populations. Similar issues are likely relevant for steelhead trout, and other salmonids, though data are fewer, and are somewhat outside my experience.

Coho salmon populations decline when fewer fish return to the spawning areas than in the previous generation, i.e. $R_{t+3}/R_t < 1$. It is useful to think about three major sources of mortality for coho salmon during their lifespan: freshwater mortality, ocean mortality, and fishing mortality. Populations decline when the sum of these three exceeds potential for growth (i.e., fecundity). While the salmon matrix focusses on the freshwater stage, it is important to remember that importance of any one depends on the current status of the others (Mobrand et al. 1997)- for example, when ocean conditions are good for salmon, freshwater survival (i.e., habitat quality) is less critical because more than enough smolts survive to allow harvest and adequate escapement. However, when ocean conditions become less favorable, freshwater habitat status increases in importance because more smolts (per spawner) are required to ensure an adequate adult return (Bradford and Irvine 2000). For example, when ocean survival is 10%, then the typical production rates of 50 to 100 smolts per female spawner will result in 5-10 returning adults per female spawner; a fishable surplus will exist even if freshwater habitats are somewhat degraded. If ocean survival falls to 2%, then good streams will produce only 1-2 adults per female, which is barely sustainable. If habitats are at all degraded, then underthese circumstances populations will decline in the absence of fishing mortality. Thus periods of poor ocean conditions will expose the status of freshwater habitats through the rates of decline of individual populations (Bradford and Irvine 2000).

A review of coho salmon life history and demography

Coho salmon spawn relatively late in the year, and use fall rains to gain access to the headwaters of stream networks. Spawning tends to be scattered, and females probably choose higher quality pockets of gravel. At typical densities there is likely little competition among them for spawning locations. Each female usually has 2000-2500 eggs (Beacham 1982). The few available data suggests that the survival from of fry from spawning to emergence in the spring is about 20% (Bradford 1995). This is higher than for species that spawn in large aggregations in lower parts of rivers (sockeye, pink and chum average 8%). The higher survival for coho is probably the result of spawning in higher gradient headwaters, where sediment levels might be expected to be lower. I would not be surprised higher survival rates were higher in some streams: values of 40% have been recorded for chinook salmon that make use of larger gravel in large rivers.

Thus on average about 400-500 (but perhaps higher) emergent fry are produced per female spawner. Immediately after emergence from spawning gravels some fish take residence in the natal stream, while many emigrate to habitats downstream. The rate of fry emigration is quite high (100-600 fry/female spawner, mean=325, Bradford et al. 2000), meaning that is some cases most fry that emerge from the gravel immediately leave the natal stream.

The fate of fry migrants is not well understood. In small streams that enter the ocean, their survival is thought to be poor unless there is a low salinity estuary area (Mason 1975), as their capacity to adapt to seawater is poor. In larger stream networks fry that migrate from headwater streams may have to opportunity to rear in higher order stream channels, particularly in off-channel, or slower velocity areas that might be available (Hartman 1965; Beechie et al. 1994). Given the high rate of emergent fry emigration, it seems possible that the downstream migrants could make a substantial contribution to overall smolt production, although this has not been well quantified to date.

The behaviour and habitat requirements of coho fry during their year in the freshwater has been well-studied, although perhaps less so from the perspective of population dynamics at low abundance. In general, the production of yearling smolts is limited by the quality and quantity of the rearing habitat. Larger streams produce more smolts, and the average production rate is about 1000-1500 smolts/km of stream (for streams large enough to be found on 1:20 000 or 1:50 000 maps; Bradford et al. 1997). But there is enormous variation in the potential of a stream to produce smolts (ranging from 500-4500 smolts/km). The period during the year when habitat becomes limiting may depend on regional factors such as climate and streamflow, but will also depend on local habitat features. The summer low-flow period, and the high-flow winter period have both been suggested as intervals when habitats limit juvenile production (Smoker 1955; Nickelson et al. 1992). In spite of the physical limitation to smolt production, interannual variation in the number of smolts produced per stream varies considerably (CV=35%; Bradford et al. 1997).

Of considerable interest for endangered populations are the dynamics at low abundance. Although smolt production is often independent of spawner abundance because of the constraint imposed by physical habitat, at some point the number of fry available becomes limiting, and smolt production is positively related to spawner abundance. Data on the production of smolts at low spawner abundances is very limited, but what there is suggests an average rate of about 85 smolts/female (Bradford et al. 2000). This corresponds to an approximate egg-smolt survival rate of about 3-4%. 'Full seeding' (i.e., the minimum density of spawners required to produce the asymptotic smolt production) occurs at about 10-20 female spawners/km of stream.

The immediate implication of a smolt production rate of 85/spawner is that when smolt-adult survival falls below about 2.5% populations will no longer be able to replace themselves. However, this production rate is mainly based on estimates of smolts leaving natal streams, and ignores the potential contribution of fry migrants that might be able survive to the smolt stage in downstream habitats. If this contribution is significant, coho populations may be able to endure lower smolt-adult survival rates than the 2.5% suggested above.

How are the population dynamics of endangered coho salmon linked to features of the freshwater habitat? This is the key question to judge the efficacy of the Matrix, or any land use or restoration plans aimed at improving the survival of endangered salmon populations. Unfortunately, most of the measures that have been developed for evaluating coho habitat are for predicting the maximum capacity, or the limiting stage for cases when there are sufficient fish to make use of all available habitat. Such measures typically include pool volume or area (Nickelson et al. 1992, Sharma 1998) or LWD loadings. As far as I am aware, there have been no studies directed at the factors that lead to high survival and smolt production at very low spawner densities.

Some indirect inference about the freshwater habitat factors that contribute to smolt production rates at low spawner abundance is available from the analyses of Bradford et al. (2000). They found smolt production rates (ie, smolts per female spawner) were inversely correlated to the rate of emergent fry emigration. That is, more smolts were produced in streams in which the rate of emergent fry migration was lower. This suggests that the habitat features that lowered the rate of fry emigration resulted in good smolt production at low spawner abundance. Thus the retention of those fry that survive to emergence from spawning gravels appears to be key for increasing smolt production. This point is reinforced by the experimental studies on Minter Creek, WA, where all emigrating fry captured at the mouth of the creek were transplanted back up into the headwaters (Salo and Bayliff 1958). As a result, the more smolts (>150/female) were produced at low abundance than in any non-experimental streams where fry were lost from the system.

We do not know exactly what causes variation in the rate at which fry leave the streams, but it seems likely that habitat complexity probably is an important issue, since it will maximize the number of locations in which fry can find suitable rearing. Habitat complexity will also minimize social interactions that can result in downstream displacement. In cases where high flow events occur during the period of emergence in the spring, the availability of flow deflecting structures, or off-channel habitat will provide velocity refugia for these small fish.

If such a high proportion of fish are leaving the stream, it seems reasonable to ask whether the quality of spawning gravels is likely limiting populations at low spawner abundance. At first glance it appears that better gains in smolt production would be had from increasing the retention of fry instream, rather that producing more fry per spawner. This is not to suggest that egg-fry survival is not important, as the production of sufficient numbers of fry will be required to fill available habitats. Another issue that has not been addressed in Bradford et al. (2000), but seems evident from the Minter Creek study (Salo and Bayliff 1958) is that smolt production may be enhanced when spawning is concentrated in the headwaters of the stream network. This will increase the likelihood that an emergent fry will be able to find a suitable rearing location in its downstream migration, and to ensure all available habitats are utilized. Land-use practices that result in headwater streams being less suitable for spawning (e.g. passage, or availability of suitable substrate, flow or water quality) will may result in the occlusion of these areas for rearing juveniles.

It is unlikely that the absolute amount of suitable habitat (i.e., % wetted area as pools, Sharma 1998) in a stream will limit coho productivity at very low abundance unless the stream is highly degraded. But there are features of the physical environment that may contribute to higher productivity at low abundance. The previous discussion suggests that frequency and distribution of habitat features that create habitat diversity (such as pools and LWD) through the stream network may be important for the retention of newly emerged fry. Currently, the matrix does have measures to describe the distribution of habitat complexity throughout the stream network to provide adequate retention of fry during the emergence period.

In summary, the likelihood that coho salmon populations will endure a period of low ocean survival conditions will be related to the capability of its freshwater habitat to produce smolts at low spawner abundance. Indirect evidence suggests that the rate of production of smolts is related to the physical attributes of the stream that retain newly emerged coho fry in the stream. Further productivity may result from the survival to smolt of fry that are displaced to downstream habitats such as large rivers or estuaries. These conclusions are inferred from reviewing population level data: there is a need to directly address these issues to better understand what attributes of stream habitat will enhance fry-smolt survival.

Can salmon populations persist in managed second and third-growth forest landscapes?

As indicated above, the persistence of salmon populations during periods of poor ocean conditions depends on the capability of the freshwater habitat to provide the conditions for good egg-smolt survival. These might include reasonable spawning gravels, complex and suitable habitats to retain newly emerged fry and to provide suitable rearing habitats through both summer low-flow and winter high flow periods, and suitable downstream habitats to allow survival of fry that emigrate from natal streams. As previously noted, extended periods of poor ocean conditions tend to amplify any deficiencies in freshwater habitats that might have resulted from land-use impacts.

In our visit to Prairie Creek, we saw how in the old-growth landscape streams had abundant large LWD, which creates pools, habitat diversity and cover from high flows. Undisturbed valley slopes result in relatively good water quality and low stream sediments. Forest cover and shade keep water temperatures moderate. In our visits to other areas it was apparent that past mangement practices have resulted in channel simplification, shallowing and reduced LWD loadings in small streams, and channel aggredation, simplification and water quality issues in downstream reaches. All of these changes could result in a reduction of productivity in some habitats, and the exclusion of downstream habitats because of water quality or temperature issues.

Most of the Redwood area has been deforested in the past 100 years, and there has undoubtedly been a loss of salmon productivity as a result of these changes (Welsh et al. 2000). Plans for a continuously harvested landscape mean that streams will never recover to the old-growth state, although some recovery of the most altered catchments is likely with appropriate harvest strategies and riparian management. However, any loss of productivity from the old-growth state will increase the risk that salmon populations will be extirpated during prolonged, but inevitable, downturns in ocean conditions.

Can salmon persist in the second and third growth managed forest landscape? The Prairie Creek studies that are underway through Humboldt State will reveal the potential of old-growth streams to produce salmon smolts, as well as other important life history information. But comparable work is required for streams that are considered to be sited in well-managed forest catchments. This type of work will better identify the conditions in the managed landscape that will sustain salmon populations, and will assist in determining if land management of any sort in the Redwoods can produce conditions that allow for sustainable salmon populations. Studies should also consider the downstream linkages in larger watersheds; large river habitats may have been important areas of production, especially when spawner abundances are low as the survival of fry that emigrate from headwater areas could make a significant contribution to the population.

The effects of cumulative land-use impacts on aquatic habitats.

The impacts of human activities on stream biota result from both instream and riparian alterations to broader, catchment scale impacts. Recently, with the availability of detailed land-use information through GIS technology and the development of indicators of aquatic ecosystem health, it has been possible to relate land-use at different scales in space and time to the abundance and diversity of stream biota. Some generalizations from this work are becoming possible, and these are detailed below:

1. The impacts of alterations of the riparian zone on stream biota are variable, and will depend on the status of the upslope catchment. In some studies, stream biotic diversity was related to the status of the riparian zone (Jones et al. 1999) immediately upstream of the sampling area, but others have found the upslope condition to be more important. (Harding et al. 1999). Obviously, some land-use impacts have the potential to dominate any ameliorating effects of the riparian zone. All authors have noted that scale plays an important role in these analyses: effects of riparian or upslope alteration in the immediate vicinity are different than impacts that are the result of upstream effects.
2. Historic land-use patterns can be important. In a study of forested catchments, some of which were farmed 50-100 years ago, Harding et al. (1999) found that there were still effects of past practices on stream biodiversity. Geomorphologists have often noted that there can be long lags between before the effects of upslope modifications manifest themselves in the stream channel; this study extends that result to stream biota.
3. There is little evidence for threshold effects. Generally, biodiversity or abundance was linearly related to the magnitude of land-use, whether that be the fraction of land altered, road density, or the fraction of impervious area in the catchment (Bradford and Irvine 2000, Crosbie and Chow-Fraser 1999, Karr and Chu 1999, Dunham and Rieman 1999). The evidence suggests there are no thresholds for cumulative effects, and decisions to restrict land alteration will be based on the trade-off between that activity and increasing impact (and risk to populations).

These results are relevant to the application of the Matrix to Redwood catchments for a number of reasons. First, the status of the in-channel physical environment and presumably aquatic biota (ie, LWD, pools etc.) at any point in time will depend on the interplay between upslope alteration and channel adjustments to changes in inputs of energy, water, sediment and wood. In an actively managed region it is unlikely that the stream channel will be in an equilibrium state with these catchment processes. Thus a detailed inchannel assessment may not provide information on the state the channel or the aquatic biota is evolving to (i.e., more or less desirable).

Second, the evaluation of the status of a salmon stream should include both the inchannel habitat metrics, and measures of status of the whole catchment. These might include road density, and various classes of vegetative cover. While the available research indicates that there likely aren't any thresholds for impact, it should be feasible to create a scale of 'risk' based on the degree of landscape alteration. It will also be important to predict how those measures will change over time with management activities to determine the direction (positive or negative) that upslope condition will have on inchannel conditions.

Assessment, monitoring, and adaptive management

Ideally, the efficacy of a plan to reduce the risk of extirpation of salmon populations should be assessed by the distribution, abundance, survival, growth and other metrics of the fish themselves. Currently the matrix or the HCP has no explicit provisions for the use of fish data to evaluate management activities.

Assessment through the monitoring of trends in adult abundance across the whole region is not likely to be successful because estimating spawner abundance is quite difficult during the rainy season, and trends in adult abundance can be driven by ocean and fishing mortality. These can be controlled for if one or (preferably) more unaffected control populations can be monitored (e.g., Bradford 1994), but this increases the magnitude of the task substantially.

Estimating juvenile abundance over large areas is theoretically possible, at least in small streams (Hankin and Reeves 1988), but is an enormous task. The interpretation of juvenile abundance data is complicated when parent spawner abundances are low, because the abundance and distribution of spawning fish, rather than habitat conditions, may be limiting juvenile abundance.

However, the panel was shown little quantitative fish data for the Redwoods region (although data may exist elsewhere). There may be merit to investigating the use of habitat by the fish themselves to identify region-specific conditions for 'functioning habitat'. Such an investigation would help solidify the relationship between the elements of physical habitat contained in the matrix, and fish productivity. The following describes steps in a proposed 'fish-based' habitat evaluation in a watershed, with a focus on coho salmon.

1. Determine the distribution and relative abundance of spawners. This might be achieved by foot surveys for adults or redds, or by careful sampling in the spring for newly emerged juveniles. The goals of this element are to determine which portions of the watershed are 'seeded' by spawners, the upstream limits of spawning, and some measure of the approximate abundance in different sectors of the stream network. The use of baited minnow traps can be particularly effective in trapping juvenile fish in slack-water areas, even under high (spring rain) flows.
2. In late summer, sample juvenile fishes in as many streams as possible, including both low and moderate order part of the drainage. Index sampling (snorkel/minnow trap/ electrofish)

will provide relative abundance data, as well information on size and size distribution. Care must be taken in the interpretation of abundance data from preferred habitats (pools for coho) as there is a risk of density-dependent habitat selection. That is, coho salmon may preferentially fill pools, and the relative abundance measures for these habitats may not be indicative of fine-scale changes in abundance in the whole stream. The data will be useful for coarse-scale (presence/absence) information.

3. Coupled with the fish sampling a suite of habitat measures would be taken at each sampling site. Preferably continuous monitoring equipment for temperature and turbidity would be installed. Other physical measures of the type in the matrix would be recorded. Conductivity may be a reasonable surrogate for nutrient status.
4. In early spring, during a low water period, some or all of the sites would be resampled to identify shifts in distribution associated with overwinter period, and to obtain an estimate of growth and pre-smolt size. Consideration should be given to some small-scale mark recapture experiments to estimate the density of presmolts (smolts/kilometre) of streams of different habitat conditions, facilitate comparisons with the compilation of Bradford et al. (1997).

Results from this type of study would provide (1) a baseline survey of the status of the salmon populations in the watershed, (2) some life history information about the relative use of different habitats and movements among them, (3) data for an analysis of juvenile habitat use relative to habitat conditions (ie, measures in the matrix), conditioned for variation in 'seeding' from scattered spawner distributions, and (4) data for the analysis of fish performance (ie growth, size, size distribution) as a function of habitat conditions. It may be possible to develop field-based tolerances for temperature and chronic suspended sediment levels from this study.

Long-term population studies are really the only means to sort out whether changes in fish populations are responding to trends in environmental conditions or from changes in human activities in the catchments (Hartman and Scrivener 1990). Of particular concern are changes in ocean conditions, or those induced by cyclical patterns of drought or flood. Consideration should be given to establishing one or more long-term monitoring sites in the Redwoods, similar to what was apparently originally proposed for Caspar Creek.

What is Adaptive Management?

The use of the phrase 'Adaptive Management' has changed so much since its inception that the original proponents now prefer 'Experimental Ecosystem Management' (Walters and Holling 1990) to describe their original intent of using management actions as large-scale experiments for learning about ecosystem responses to perturbation. This approach explicitly recognises that ecosystem-level responses are unlikely to be predicted by reductionist or mechanistic research programmes and that a holistic 'learning by doing' approach at the ecosystem level is required.

The first step to initiate an adaptive management program is to describe, via conceptual or mathematical model, reasonable hypotheses about the responses of the ecosystem to a management action. The management actions are then structured in the form of a large-scale experiment in which data collection programs are designed to help discriminate among the competing hypotheses about how the system actually works. A key to success is ensuring that at least some of the management action is employed at some times or space in a strong enough manner to provoke a measurable response in the ecosystem. The simplest, and perhaps most commonly employed adaptive management scheme is the treatment-control design where either time or space is used as a control. The Caspar Creek study is an example of this design, although this is a research study. Johnson (1999) suggests adaptive management should be an integral part of routine management activities.

'Adaptive management' as used in the PALCO HCP and many other recent environmental impact statements is best described as a 'monitor and modify' scheme (Johnson 1999. Unfortunately, in many cases, details of how this process would function are absent. The absence of explicit goals and study design increases the likelihood that institutional momentum will falter over time. One advantage of a true experimental management program is that the preliminary model development/hypothesis generation component usually results in an explicit study design and sampling program to maximize the information yield of the proposed experiment.

A pitfall of the 'monitor and modify' program is illustrated by the series of proposed 'null' hypotheses to be addressed by monitoring in section 6.3.5.2.8 of the PALCO HCP. Each hypothesis begins with the clause 'There is no significant increase' in some habitat measure as a result of the management regime proposed in the HCP. The implication of this phrase is that the burden of proof is the demonstration of an adverse effect of the management action. This is standard practice for experimental science (as it is manifest in classical statistics), but is inappropriate for environmental protection. The inevitable collection of few, perhaps highly variable, data will result in the failure to reject the null hypothesis, and likely, the erroneous acceptance of it.

In a true adaptive management program hypotheses such as "sediment inputs to class II streams are likely increase (linearly, or non-linearly) with the proportion of the catchment clearcut" are devised, and tested by logging at different rates at a number of sites. The outcome of this experiment is a functional relation between management activities and ecosystem response that can then be used as the basis for decision-making about other parts of the managed area. The rate of learning in an explicitly experimental approach is much greater than from the fine-tuning that results from 'monitor and modify' regimes (Johnson 1999).

3. The application of the matrix to manage salmon streams and their catchments.

The salmon matrix describes a reasonable set of attributes of a productive salmon stream. It should be noted that the quantitative elements of the matrix are probably most appropriate to low and mid-order streams; whether some of the metrics (such as pools, LWD) are as applicable to larger streams is not as clear. Information on larger rivers is less common, because of logistic issues.

Salmon streams are intrinsically variable in nature, both in time, and across the landscape. Salmon populations have been able to adapt to this variation, although there can be a tremendous range in productivity as a result of the variations in habitat. For example, Bradford et al. (1997) reviewed coho smolt production from over 80 streams and found the smolt production rate (smolts/km) among streams ranged from less than 500 to greater than 4500 smolts/km- much of this variation is probably due to the differences in the quality of the stream habitat.

Thus it is inappropriate to attempt to manage salmon streams to a single condition as described by threshold or benchmark standards. Rather, the matrix should be expanded to include the range of variability in habitat standards- this range would emulate what one might expect to encounter in a suite of 'properly functioning streams', that might be part of a large drainage basin, or region.

The matrix should then be applied at a large basin scale, and the range of variability in streams should be calculated and compared to reference conditions. In this sense the matrix becomes a tool for the relative status of stream habitat at relatively broad scales. This broader application avoids the need to 'explain' why a specific stream (or reach) does (or does not) meet a threshold criteria- the causes for the state of habitat in a reach are likely multiple, and may lie in previous, unknown events such as floods or debris events.

Care must be taken to distinguish between variability among sites within a stream or basin, and catchment-to-catchment variation. Variables such as fines in the stream substrate and LWD loadings will have considerable variation among samples in a stream, and among streams in a region. A full analysis of the components of variation using ANOVA or similar frameworks will assist in separating stream and reach-specific variation. The importance of this analysis is illustrated by an extreme hypothetical case where most of the variation is due to sample or site variability in a stream. In this case there may be only little variation among streams, or even if there is, it will be difficult to detect with only a few samples being taken from each stream. Careful characterization of the within and among stream variation will allow quantification of the 'range of variability' in 'properly functioning habitat'. A suitable measure of variability might be ±1 SD, or the interquartile range, both of which will capture most of the 'typical' variability in an attribute. I caution against the use of significance tests for 'control' vs. 'treatment' types of data—standard statistical tests (e.g., $\alpha = 0.05$) are very conservative for detecting differences when data are variable. This is especially important in cases where the consequences of erroneously concluding 'no differences' are severe (for example, when evaluating habitat degradation for endangered species). Mapstone (1995) provides a good review of the use of classical statistics in these situations. Although other procedures exist for comparing data (such as likelihood ratios), I would suggest the use of simple graphical means for evaluating differences in the range of variation between control and sample stream data.

Sometimes, when benchmarks or standards are employed, the ecosystem is managed up or down to that standard. For example, the use of a maximum temperature, or a minimum pool volume, can result in mangement to what are essentially minimum standards for habitat quality. The use of operating ranges should help to alleviate this problem. Instead of tallying the number of cases where a suite of streams exceeds a threshold (i.e., mangement by compliance to a standard), the range or variability of data collected from the streams of interest would be compared to a desirable range from 'properly functioning' streams. The congruence of the ranges of variability will provide some indication of status of the streams of interest for that habitat measure.

Metrics for monitoring and adaptive management.

A fundamental problem with compliance monitoring is that the response of aquatic habitats to land-use alterations might have lags of 5 to 100 years. It is unlikely that inputs of wood or large sediment, or channel forming process are likely to change in sufficient time to allow meaningful alteration of management practices to achieve more desirable goals. For these geomorphological processes a better approach may be more retrospective- what is the status of stream habitats in relation to past management practices?

Two variables that are likely to rapidly respond to land-use practices, and are of immediate relevence to fish populations, are water temperature and turbidity. Both are straightforward to collect, and provide indications of changes in the passage of water through the catchment. Ideally, monitoring would begin prior to the management actions, and would also extend to unmanaged watersheds to help control for climatic variation.

The matrix does not contain any provision for the analysis of the status of the upslope lands. As reviewed above, there appears to be consistent linear relations between the status of aquatic biota and the degree of disturbance in the upland, including road densities. This disturbance could extend to changes in the catchment that have occurred decades prior to the present. A useful indicator of likely trends in the status of stream habitats could be derived from present and future projections of the types of forest cover and road densities in the catchment.

Given the impacts of hillslope activities on aquatic habitats may be particularly severe in the Redwood region (Welsh et al. 2000), more research appears required on quantifying the impacts of different land covers (including vegetative categories) on aquatic habitats in the Redwood region. It should be possible to assemble land-use information on a catchment scale (including stand age) and use existing and new aquatic habitat data to conduct a synoptic study to calibrate land-use metrics appropriate for the Redwood regions. The matrix should include appropriate quantitative indices of land-use resulting from this analysis. Indices would be calculated from planned land-use activities in the catchment, and the age structure and likely succession of the vegetative cover. If the index moved towards a more disturbed condition at a decadal scale, it would be unlikely that aquatic habitats would be maintained or would evolve to more desirable states.

This approach bears some resemblance to the Disturbance Index (DI) in the PALCO SYP/HCP, except the time frame and coverage would be expanded. Whereas the time horizon for the PALCO DI is relatively short (10-20 years), there is sufficient evidence from geomorphological studies in the Redwood area, and from research relating aquatic ecosystem health to land use reviewed earlier, to suggest that alterations 50-100 years ago should be at least considered as part of the metric. Because there is no evidence for threshold effects for the cumulative impacts of landuse on aquatic biota, there is no scientific basis for assuming a threshold for cumulative indices such as the DI. Rather, metrics should be devised at tracked over time, and used as guidance for making decisions about land-use management.

4. Some Comments on Specific Components of the Matrix

Water Quality—temperature.

Salmonids are coolwater species, and water temperature is a key macroenvironmental variable that will determine the suitability of a stream network for them.

The matrix proposes that the maximum weekly average temperature (MWAT) for coho (and presumably other salmonids) be 16.8 °C, with a desired range of about 12-15 °C. It should be noted that these are intended as mid-summer rearing temperatures. There is often a tight coupling between the time of emergence of young juvenile salmon from spawning gravels and the thermal regime experienced over winter. Logging has been shown to affect winter water temperatures and the timing of emergence, which can have adverse consequences on subsequent survival (Hartman and Scrivener 1990).

The calculation of MWAT as a criteria appears somewhat arbitrary (one third the way between the optimal and lethal temperatures), but it is probably in the right range. Generally salmonids can survive in water up to temperatures in the low 20's, but in order to grow there must be adequate food resources as metabolic demands increase with temperate. Density-dependent growth has been observed for juvenile coho rearing in small streams (Hartman and Scrivener 1990), which means that food can be limiting. Increasing temperature will heighten competition for food unless there is a corresponding increase in invertebrate drift. Competitive interactions among juveniles caused by greater food requirements might lower the capacity of the stream to produce smolts.

Warmer temperatures can make streams more suitable for species that do not normally inhabit cold salmonid streams, and predation and competition can increase even when temperatures are within a range that is physiologically acceptable to salmonids (Reeves et al. 1987). Thus there is an ecological component to the impacts of temperature, and there is reason to be concerned about temperatures above the preferred range (i.e., >15° C).

Satisfying MWAT requirements for a headwater stream (or a group of low order streams) does not guarantee satisfactory water temperature conditions for the whole stream network. In summer months it would be expected that temperatures will increase downstream as solar inputs increase, and the influence of riparian shading over larger rivers decreases. There is a risk that the application of a single standard to headwater streams could result in considerably warmer mainstem habitats, and the reduction of the amount of suitable habitat in the drainage basin. Clearly, properly functioning salmonid habitat in a large watershed stems from relatively cool temperatures in headwater streams, with increasing temperatures further downstream- the amount of habitat available will depend on the rate at which the water will warm during its transit downstream. Although the review panel was not presented specific data, based on the commentary at Prairie Creek, it seems likely that under pre-logging conditions the headwater streams were likely quite cool in summer as a result of shading and upland forest cover, and that these cool low order streams helped maintain more suitable temperature regimes in larger rivers than we see today.

Thus the agencies may wish to reconsider the temperature criteria with the goal of maintaining suitable conditions in more of the downstream areas than the application of the present values would permit. A better understanding of the life history of juvenile salmonids in downstream (mid-order) streams will be required to implement these changes, though.

Sediments in the substrate

Sediment, and the turbidity associated with suspended sediment is a natural component of any stream. But sediment levels are often elevated by human activities in catchments, and a great deal of research has been conducted on the effects of increased inputs on fish, other biota, and physical habitats (e.g., Waters 1995).

There is a well-established negative relation between the amount of fine material in the stream substrate and the survival of salmon eggs and alevins, which forms the basis of a variety of sediment metrics in the matrix (Chapman 1988). Unfortunately simple sampling of the streambed is not useful for the direct prediction of egg-fry survival for salmonids because spawning process extensively modifies the stream substrate in the area where eggs are deposited. Thus the many studies on egg-fry survival as a function of gravel mixtures that are typically conducted in flumes can not be used to develop thresholds for 'properly functioning' stream substrate.

An alternative to applying standards from laboratory studies is to rely on samples from unaltered streams as a baseline reference condition. This is the approach described by Peterson et al. (1992), who set a target condition at 11% <0.83 mm, based on data from Washington streams. They note that regional (geology, climate) influences will affect the baseline state. The matrix suggests a range of 11-16%, which appears to be a compromise between Peterson et al's recommendations and the data of Burns (1970) for Redwood streams. Given the highly erodable geology of the Redwood region, is seems reasonable to propose the naturally occurring rates of fines in the sediments might be higher than in other regions with, for example, granitic bedrock.

Burn's (1970) study and additional work like it could be more fully exploited to describe the range of variability in Redwood streams unimpacted by recent forest harvest practices. The mean percent fines in 6 streams ranged from about 10 to 20%, but unfortunately, it is not possible to extract the variability of individual samples from the presentation of the data. An effort to retrieve the original records of this study is highly recommended to allow calculation of components of variability (within and between streams, and across years). Such an analysis would allow computation of the potential range of variation among streams, and the size of samples within a stream needed to adequately describe substrate conditions. Care should be taken in calibrating different sampling techniques, particularly with respect to the finest sediment size categories (Young et al. 1991).

Are all 4 measures (fines<0.83mm, fraction < 6.4mm, D_g, Fredle index) required for the analysis of stream substrates? All are likely highly correlated with each other, but each are purported important for different components of egg-emergent fry survival and quality (Chapman 1988). However, since stream sampling does not capture conditions in egg pockets, there will not be an exact correspondence with the various measures of sediment quality and survival. It seems likely that both for simplicity of interpretation, and to make maximum use of historical data, the simple measure of fines <0.83mm may be the easiest way to evaluate stream conditions for the incubation of salmonid eggs and alevins, and as well as conditions for invertebrates and other organisms.

I am not familiar enough with V* and pebble counts to comment on these measures.

Suspended Sediments and Turbidity

Turbidity is the measurement of light scattering materials in water. Turbidity and suspended sediment levels are often highly correlated, although the exact relation is usually system specific. Suspended sediment measurements have been conducted in a variety research projects that are usually aimed at determining sediment budgets in response to land-use activities, mass wasting and storm events (i.e., Lewis 1998). The intensive required for developing sediment budget precludes it from routine use as a monitoring tool.

There was some suggestion that chronic turbidity is an issue in managed catchments in the Redwoods. Turbidity during low flow periods may be a useful indicator of the stability of upslope land, and is certainly easier to measure than turbidity pulses during storm events. Inexpensive, solar powered datalogging turbidity recorders are now available. A research program that measures low-flow turbidity in relation to catchment land-use, road density, geology and mass wasting efforts in 20 or more streams may be of use determining the utility of the metric. The results may also generate useful relations between management practices (e.g. vegetation cover, cut history) and stream inputs, thus providing a measure that links upslope practices with aquatic habitat status.

As well as providing information on catchment stability, there are also direct biological consequences of chronic turbidity (Lloyd 1988). Diminished light penetration can reduce primary productivity in the stream, which can potentially impact the autotrophic food chain for fish. Turbidity (resulting from sediment levels of 100-200 mg/L) reduced the foraging success and growth of coho and steelhead juveniles (Sigler et al. 1984), however, in experimental trials chinook salmon appear to prefer moderately turbid water (Gregory and Northcote 1993), perhaps as a mechanism to avoid predation. Chinook salmon may be better suited to olfactory feeding from the benthos than other salmonids.

The ecological implications of these species-specific differences are evident in habitat use studies. In sampling I have conducted in the Fraser River, B.C. and its tributaries, juvenile chinook salmon were very common in the naturally turbid mainstem (50-300 mg/L), whereas coho and steelhead were largely restricted to clear or low turbidity tributaries (Bradford, unpubl. data). For the naturally turbid Taku River of southeast Alaska chinook salmon were common in turbid main channel habitats, and coho salmon were rarely found there (Murphy et al. 1989). Instead, coho salmon were most abundant in off-channel creeks, beaver ponds and other clearwater habitats. This result suggests that coho (and possibly steelhead) may be excluded from habitats where sediment levels are continuously elevated. Since larger streams may be important as rearing habitats for downstream migrants from headwater streams, the impacts of elevated turbidity could be quite important. Similar effects might result if channel alteration has reduced the availability of (clear water) off-channel habitats in larger rivers.

5. Conclusions and recommendations

The properly functioning matrix provides a reasonable description of many of the conditions considered necessary as salmonid habitat in reaches of small and mid-order streams. The matrix does not quantitatively consider the effects of upslope conditions and management activities on aquatic habitats, nor the effects of stream in managed lands on larger streams and rivers downstream in the stream network. To fully protect the salmon (and other aquatic species) and their habitats the matrix should be expanded in scope to include quantitative measures for upslope and downstream effects to address the long-term, cumulative changes that will occur as a result of changes in land use. Quantitative measures should be evaluated by a range of variability approach.

To address some of the shortcomings of the matrix the following activities are recommended:

1. More fish-based research work should yield better information on the biology of salmon in the Redwoods, the actual habitat requirements of the fish, and the impacts of land-use on productivity.
2. Low flow turbidity and temperature should be evaluated as real-time indicators of land management.
3. Cumulative effects of land use should be evaluated. Metrics that track changes in land use and vegetative cover should be developed, tested, and implemented to evaluate how future management activities are likely to impact aquatic habitats.

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OTHER DOCUMENTS

33. Public/Private Comments on Matrix for Pacific Lumber HCP (INCLUDES SEVERAL COMMENTS)

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STATEMENT OF WORK

Consulting Agreement Between the University of Miami and Michael Bradford

General

In March 1997, federal and state agencies developed an aquatic matrix for the Pacific Lumber Company Habitat Conservation Plan (hereafter "salmon matrix"). The matrix puts forth a condition for the landscape which has been determined to be properly functioning in order to meet the habitat needs of anadromous salmonids and other aquatic species in northern California on Pacific Lumber Company properties in Humboldt County.

Consultants shall need to address the following questions for the salmon matrix review:

1. Are the metrics used in the matrix appropriate for assessing aquatic and associated riparian habitat conditions to meet the needs for threatened and candidate salmonid species? If not, which metrics would be appropriate and at what landscape scales?

2. Are the values provided for the metrics appropriate for assessing aquatic and associated riparian habitat condition to meet the needs of threatened and candidate salmonid species in coastal redwood systems? If not, which values would be appropriate and at what landscape scales?

3. Which metrics are the most appropriate for the assessment, monitoring, and adaptive management of aquatic candidate salmonid species in coastal redwood systems?

4. How should in-stream and riparian metrics be functionally and practically linked with upslope and watershed scale processes that, in part, determine their expression?

Specific

The consultant's duties shall not exceed a maximum total of three weeks- several days for document review, a 4-day meeting, and several days to produce a written report of the findings. Please note that the report produced must be based on the consultant's individual opinions of the science in his area of expertise and not that of the group; thus, no consensus report shall be produced.

The itemized tasks of the consultant include:

1. Reading and analyzing the relevant documents provided to the consultant;

2. Participating in a 4-day meeting with the other consultants and NMFS officials in San Francisco/Arcata, CA, from November 27-30;

3. No later than January 15, 2001, submitting a written report of findings, analysis, and conclusions. The report should be addressed to the "UM Independent System for Peer Reviews, " and sent to Dr. David Die, UM/RSMAS, 4600 Rickenbacker Causeway, Miami, FL 33149 (or via email to ddie@rsmas.miami.edu).

Signed____________________________________ Date______________

BUDGET

1. Salary ($600 per day for 21 days)	$12,600
2. Plane fare (Vancouver, BC to Arcata, CA)	$800
3. Lodging (November 26-December 1: 5 nights)	$750
4. Meals ($30 per diem for 6 days)	$180
5. Car rental ($50 for 6 days)	$300
6. Additional transportation	$200
TOTAL	$14,830

ANNEX I: REPORT GENERATION AND PROCEDURAL ITEMS

1. The report should be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report should consist of a background, description of review activities, summary of findings, and conclusions/recommendations.

3. The report should also include as separate appendices the bibliography of materials provided by the Center for Independent Experts and the center and a copy of the statement of work.

4. Individuals shall be provided with an electronic version of a bibliography of background materials sent to all reviewers. Other material provided directly by the center must be added to the bibliography that can be returned as an appendix to the final report.

Please refer to the following website for additional information on report generation: http://www.rsmas.miami.edu/groups/cimas/Report_Standard_Format.html